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Interoperability Testing Using the Hardware-in-the-Loop Test Tool

by

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ABSTRACT

In the past, missile defense testing was limited to models and simulations, which provided maximum flexibility but often lacked realism, or to live-fire testing, which provided realism but proved very expensive. Over the years, the Ballistic Missile Defense Organization (BMDO), in concert with its Army and Navy Executive Agents, has developed a test tool that not only bridges the gap between these two methods but has the capability to fully integrate theater missile defense weapons and systems using tactical hardware and software.

The Joint National Test Facility (JNTF) currently houses this test tool, called the Theater Missile Defense System Exerciser (TMDSE). This tool is used in Hardware-in-the-Loop (HWIL) tests to evaluate the interoperability and assess the operational performance of the Theater Missile Defense (TMD) Family of Systems (FoS). It stimulates tactical weapon systems in a controlled testbed environment, enabling them to react as in live theater conflict. TMDSE is the first platform to provide a ballistic missile defense test capability that is fully interactive, geographically distributed, multi-service, and that operates in real-time.

HWIL tests using the TMDSE have been successfully conducted nationally with such TMD FoS assets as the Army's Phased Array Tracking to Intercept of Target (PATRIOT) and Theater High Altitude Area Defense (THAAD), the Navy's AEGIS weapon system, the United States Marine Corps (USMC) Theater Ballistic Missile Defense (TBMD) segment, and the Air Force's Aerospace Fusion Center (AFC) (formerly SHIELD), among others.

This presentation introduces the BMDO's TMDSE tool and includes actual test data results. In addition, it discusses HWIL tests conducted at the JNTF, the test approach, and the methods employed to achieve (1) interoperability testing of TMD FoS on the national level, (2) risk mitigation for live-fire testing, and (3) significant cost savings. The presentation also discusses capabilities for interoperability testing planned for the future.

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INTRODUCTION



Joint National Test Facility Mission

- Provide missile defense related analysis, system level engineering, integration, and test and evaluation support for the development, acquisition and deployment of missile defense systems and architectures.
- Support the development of joint and combined missile defense doctrine, requirements, and concept of operations (CONOPS).
- Support combatant commands by integrating missile defense concepts, space asset exploitation, and battle management/command, control, communications, computers, and intelligence (BM/C⁴I); and by conducting joint and combined simulations and wargames, and by participating in exercises as directed.

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Testing of missile defense concepts has matured rapidly in the last ten years. National emphasis on defending against missile attacks has increased the need for extensive and sophisticated testing. The Ballistic Missile Defense Organization (BMDO) uses a Hardware-in-the-Loop (HWIL) tool based at the Joint National Test Facility (JNTF) at Schriever AFB, Colorado, to test interoperability of missile defense systems in support of the BMDO requirements.

The primary function of HWIL testing is to provide missile defense integration and test and evaluation support for the acquisition and deployment of missile defense systems and architectures.

The secondary function is to support combatant commands by integrating missile defense concepts; space asset exploitation; battle management/command, control, communications, computers and intelligence (BM/C⁴I); and by conducting joint and combined simulations as directed.

The Theater Missile Defense System Exerciser (TMDSE) is the HWIL tool for testing the interoperability and evaluating the integration of Family of Systems (FoS) missile defense systems.



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PURPOSE



Demonstrate how the JNTF—using the BMDO's Hardware-in-the-Loop (HWIL) test tool for interoperability testing—can benefit the warfighting community.

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The purpose of this briefing is to explain Theater Ballistic Missile Defense (TBMD) FoS HWIL testing and how it can benefit the warfighter.

During an HWIL test, realistic scenario data are injected by the TMDSE to familiarize the warfighters with their specific systems and Service doctrines to defend against Theater Ballistic Missiles (TBMs) and Air-Breathing Threats (ABTs).

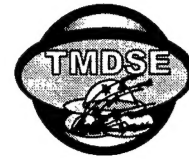
TMDSE HWIL testing stimulates operational Theater Missile Defense (TMD) tactical hardware and software weapons systems, using realistic and near-real-time simulations. It also provides integration and test evaluation of the FoS.

HWIL testing will enable members of the FoS to perform their assigned duties confidently in an actual wartime environment.



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OUTLINE



- FoS HWIL Test Overview
- HWIL 99a Testing at the JNTF
- Future Test Tool Capabilities
- Future Testing at the JNTF
- Conclusions

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FoS HWIL TEST OVERVIEW



- Definitions
- Segments
- Participants
- Communications
- Functionality
- Interoperability Testing

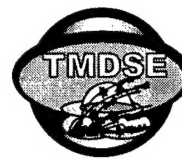
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DEFINITIONS



- Air-Breathing Threats (ABTs)
- Family of Systems (FoS)
- Hardware-in-the-Loop (HWIL) Testing
- Interoperability
- Joint Data Network (JDN)
- Near-Real-Time

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DEFINITIONS

Air-Breathing Threat (ABT)—An airborne platform that operates within the atmosphere and depends upon the ambient atmosphere for propulsion and flight control. This type of threat can be either a cruise missile or piloted aircraft.

Family of Systems (FoS)—A set of elements which can cooperatively provide a defense in a variety of theaters against a variety of missile threats.

Hardware-in-the-Loop (HWIL) Testing—A formal test method of incorporating actual hardware in a communication network for assessing a system capability or requirement. The BMDO uses HWIL tests as its primary method for verifying FoS interoperability requirements.

Interoperability—The ability of systems, units, or forces to provide services to, or accept services from, other Services, units, or forces and to use the services so exchanged to operate effectively together.

Joint Data Network (JDN)—The JDN is a network of communications/electronics systems that carries TADIL-J (Link-16) and space-based early warning information around the theater. Information is generally passed over this network in near-real-time.

Near-Real-Time—Pertaining to the timeliness of data or information that has been delayed by the time required for electronic communication and automatic data processing. This implies that there are no significant delays.



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DEFINITIONS (cont'd)



- Real-Time
- Tactical System
- Theater Ballistic Missile (TBM)
- Theater Missile Defense System Exerciser (TMDSE)
- Time-Slot Allocation (TSA)

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DEFINITIONS (cont'd)

Real-Time—(1) Pertaining to the timeliness of data or information which have been delayed only by the time required for electronic communication. This implies that there are no noticeable delays. (2) Pertaining to the actual time during which a physical process transpires, for example, the performance of a computation during the actual time that the related physical process transpires, in order that results of the computation can be used in guiding the physical process.

Tactical System—Authentic hardware and/or software components defining a segment, used in a real-world deployment situation (that is, no simulated equipment).

Theater Ballistic Missile (TBM)—An inertia-guided missile designed to be used against targets within a particular theater (such as the Persian Gulf, Northeast Asia, or other specified area). A smaller version of the Intercontinental Ballistic Missile, usually carrying one warhead (nuclear, chemical, or biological), depending upon the target composition.

Theater Missile Defense System Exerciser (TMDSE)—The Hardware-in-the-Loop test tool used to perform interoperability testing for missile defense systems. The BMDO developed the TMDSE.

Time-Slot Allocation—A synchronization method established to allow messages to be transmitted from a specific address (segment) within a specific time frame. Similar to telemetry commutation or sub-commutation. For HWIL tests, time-slot allocation means using a Joint Data Network design that stresses the automated network management functions emulated by the Tactical Communications Environment Segment.



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SEGMENTS



Seven Tactical Segments currently test with the TMDSE in configurations that combine tactical hardware, operational software, and simulation:

- AEGIS
- AFC (*formerly SHIELD*)
- CRC
- JTAGS
- PATRIOT
- THAAD
- USMC TBMD

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The Tactical Segment acronyms are defined as follows:

AEGIS: U.S. Navy shipboard tactical system, not an acronym

AEROSPACE FUSION CENTER (AFC): U. S. Air Force development tool for missile defense and warning (*formerly SHIELD*)

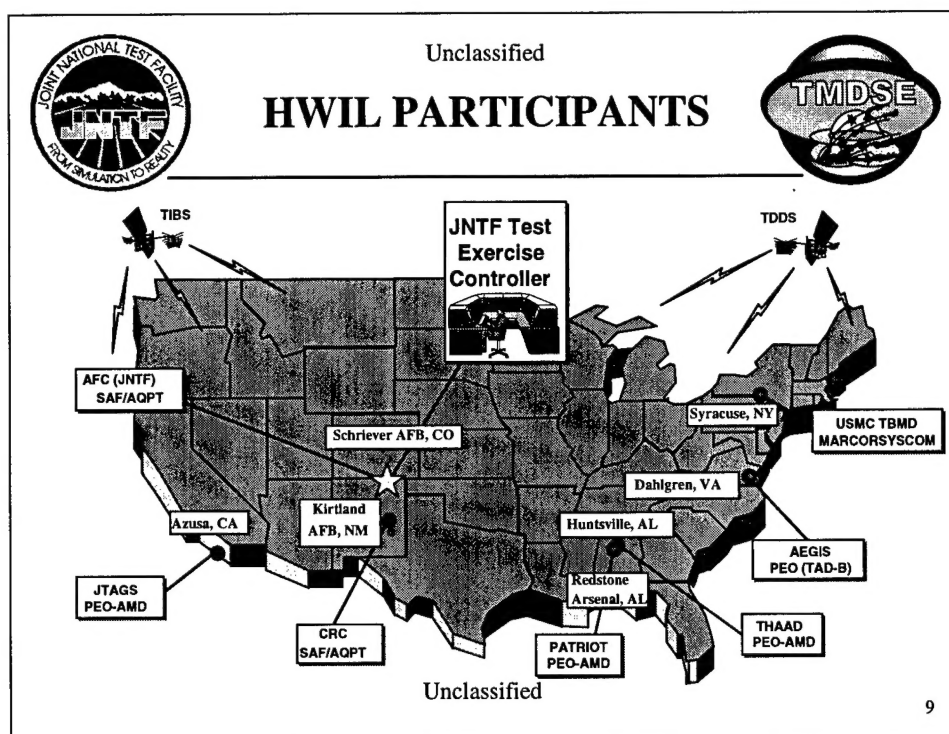
CRC (Control and Reporting Center): U.S. Air Force command and control simulation center

JTAGS (Joint Tactical Ground Station): Joint U. S. Army/U. S. Navy theater-based early warning system

PATRIOT (Phased Array Tracking to Intercept of Target): U. S. Army tactical system

THAAD (Theater High Altitude Area Defense): U. S. Army tactical system

USMC TBMD (United States Marine Corps Theater Ballistic Missile Defense): U.S. Marine Corps tactical system



This map displays the location of the seven Tactical Segments which compose the FoS, as well as other HWIL test participants.

The JNTF is located at Schriever Air Force Base, Colorado, and provides communications and interconnectivity among the seven Tactical Segments.



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COMMUNICATIONS



HWIL testing emulates the network, Gateways, and message traffic the warfighter uses in the field:

- Joint Data Network (JDN)
 - TADIL-J (Link 16)
 - TIBS
 - TDDS
- Gateway
- TADIL-J Messages

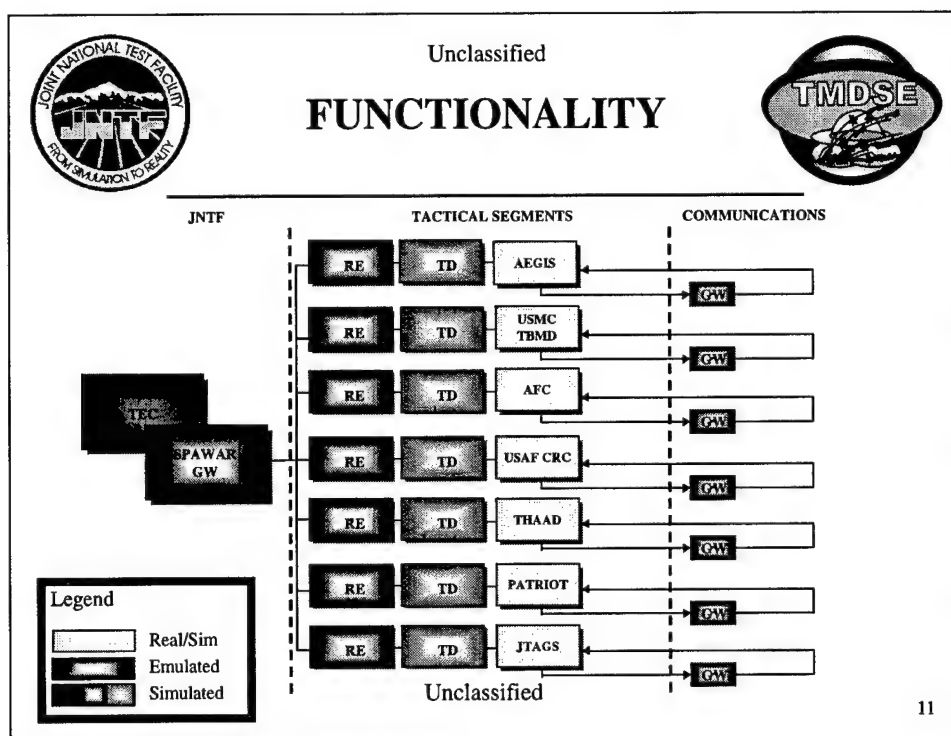
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JDN—Link-16 is the Joint Tactical Information Distribution Service (JTIDS) radio standard communications method. The Theater Event System (TES) is the combination of the Tactical Related Applications (TRAP) Data Dissemination System (TDDS) and the Tactical Information Broadcast Service (TIBS) that is being replaced by the IBS (Integrated Broadcast System) for early warning.

Gateway—The TMDSE Space & Naval Warfare Systems Command (SPAWAR) Gateway is a tool which uses the actual protocols as outlined in Military Standard (MIL-STD)-6016. One such protocol is Time-Slot Allocation (TSA), the standard method of Time Division Multiple Access (TDMA) for multiple users of the JDN. TSA was the primary focus of the HWIL 99a test.

Messages—The Tactical Segments plan to implement TADIL-J messages for command and control (J9.0) and engagement coordination (J9.1) into TMDSE, building a more realistic emulation for the Tactical Segments. The capability of the Services to handle TADIL-J messages is maturing.



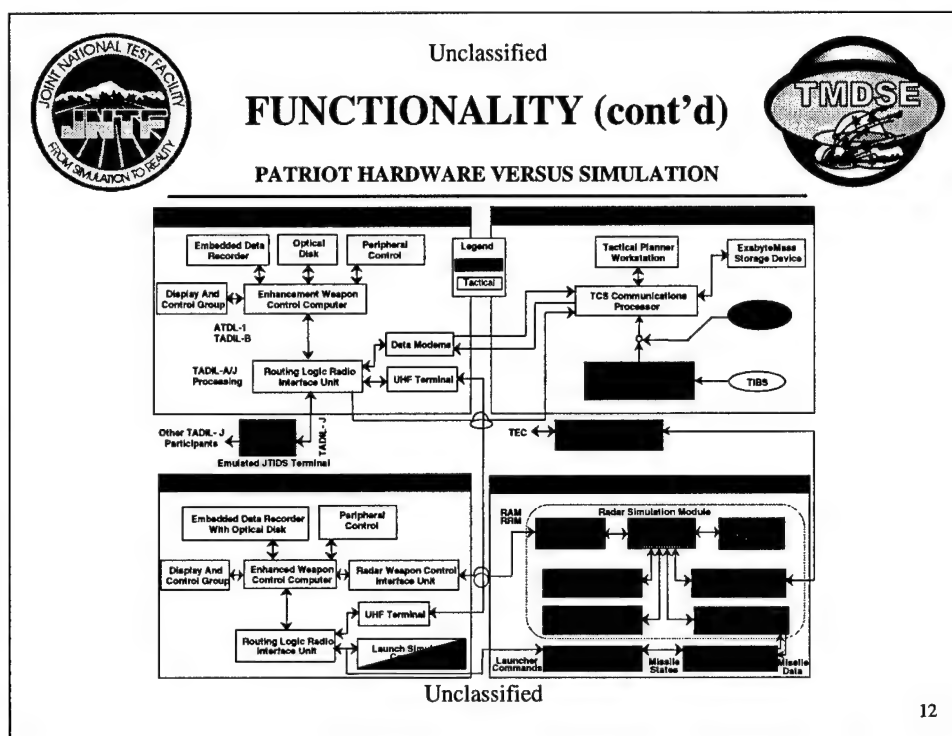
This diagram shows the current HWIL participants and designates which elements are real, emulated, or simulated during an HWIL test. Each Tactical Segment possesses its own unique Remote Environment (RE) and Tactical Driver (TD), which allows the JNTF to interface with geographically distributed Tactical Segments.

The controlling participant is the Test Exercise Controller (TEC). The TEC is the component that delivers, coordinates, controls, executes, and terminates exercise scenarios. The Test Conductor oversees and executes the test from the TEC position.

The SPAWAR Gateway (SPAWAR GW) emulates the JDN by using the protocols and timing sequences required by MIL-STD-6016. Through this emulation, the JNTF ensures the data are processed as realistically as possible. The seven Tactical Segments used to test missile defense are connected in the same manner. The connectivity of the SPAWAR GW to the router and hub that transmit data back to the TEC is not shown.

Prior to a test event the TEC downloads multiple scenarios to the REs. At the time of the test, the Test Director issues voice directions for configuring the specific scenario for the test run. At the start of the test, the REs transfer data into the TDs where it is injected into the radars and Command and Control of the Tactical Segments.

The Tactical Segments may simulate some functionality during the tests (for example, missile flyout).



This diagram is an example of a Tactical Segment showing the PATRIOT configuration. The shaded blocks are simulated and all other blocks represent the Tactical Segment's hardware and software.

The tactical equipment, operational software, and operations personnel are located at the Tactical Segments, which are positioned throughout the United States. The geographical location of the Tactical Segments in the U.S. has no bearing on where the units participate in the scenario's theater location.



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INTEROPERABILITY TESTING



- Interoperability testing evaluates the:
 - Ability of Tactical Segments to exchange information and detect, track, monitor, and negate TBM and ABT threats
 - Management of missile inventories
 - Common Tactical Picture (CTP)
- References for interoperability testing include:
 - *Capstone Test and Evaluation Master Plan for Theater Missile Defense (TMD) Family of Systems (FoS)* - for FoS test requirements
 - *Interoperability Program Plan* - provides an acquisition timeline for the interoperability capability

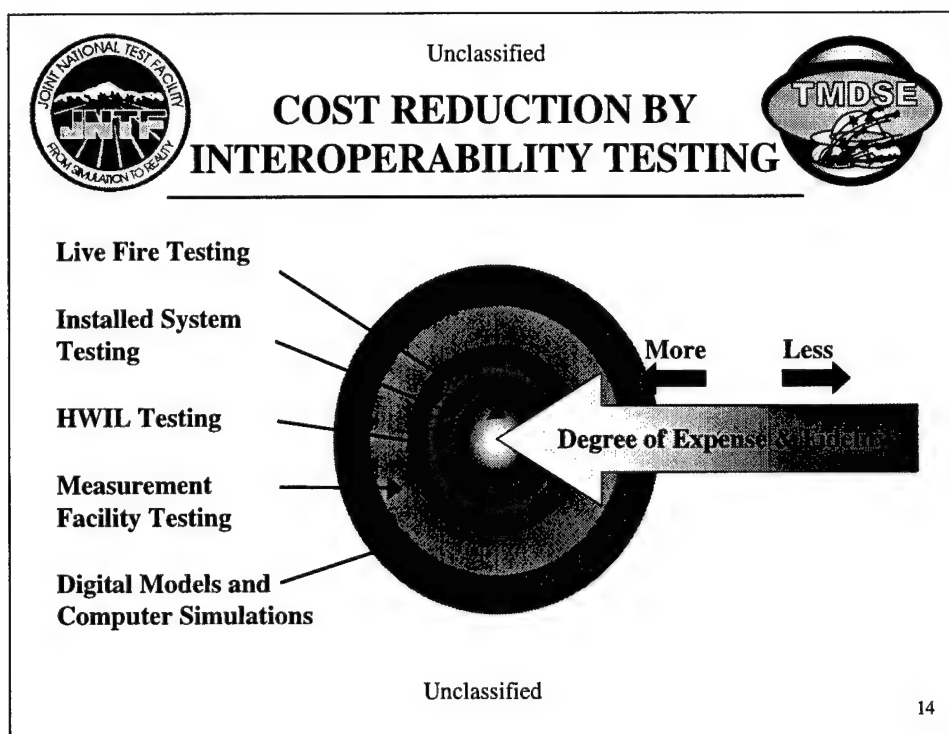
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When several segments share the data on a threat track via the JDN (Common Tactical Picture [CTP]), it is easier to prepare for the engagement and interception of that threat. By sharing data, Tactical Segments can sometimes engage and intercept earlier than if they only operate autonomously.

HWIL interoperability testing accomplishes the following:

- Confirms the ability of Tactical Segments to work together efficiently
- Reduces the cost of testing (for a live fire test)
- Mitigates the risks of fielding immature or non-compatible systems



The cost reduction realized through HWIL testing is illustrated in the above diagram. The center of the diagram represents the massive expenses incurred by live fire testing (such as actual system expenses, target vehicles, missiles, data collection equipment, personnel, and expenditure of travel funds). The rings moving away from the center represent decreasing costs of various methods of testing.

HWIL testing is not the least expensive method, but it provides a more cost-effective way to determine the operational efficiency of a tactical system than tests using live fire. HWIL testing also uses actual tactical systems' hardware and software.

An HWIL test reduces costs because it simulates the use of target vehicles, interceptor missiles, and enemy and allied aircraft. Yet these simulations appear to the tactical system operators as real target vehicles and defensive interceptors. Additionally, many outages experienced in field conditions may be encountered during an HWIL test. This realism makes HWIL testing a credible and cost-effective means of testing.

HWIL tests eliminate the risk of live fire test failures, accidents, and weather-related schedule delays. Moreover, exercises can be replayed in a controlled environment to detect errors in system operations, software, and human interaction.

HWIL tests have a primary limitation in that they can only exercise a subset of the possible defending forces which are expected to participate in a real-world theater conflict. By contrast, the number of threats are unlimited.



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HWIL 99a TESTING AT THE JNTF



- Test Overview
- Objectives
- Test Capability Increment
- Scenarios
- Results
- Summary

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HWIL 99a TEST OVERVIEW



- HWIL 99a Test Definition
 - Purpose of test
 - Participants
 - Rules of Engagement
 - Schedule of HWIL tests

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Purpose: The purpose of the HWIL 99a test was to assess the capability of the TMDSE to support three test objectives. These objectives covered the TBM and ABT missions of the FoS, as well as the ability of the Tactical Communications Environment Segment (TCES) to accurately emulate the JDN.

Participants: Test participants included AEGIS, CRC, JTAGS, PATRIOT, AFC, THAAD, and the USMC TBMD.

Rules of Engagement: Each weapon system was assigned a Defended Asset List (DAL). A command and control capability to resolve conflicts in Identification Friend or Foe (IFF) was not included in the test. Weapons systems engaged targets based upon internal Service doctrine.

Schedule: The HWIL 99a test was performed in January 1999. The HWIL 99b test is scheduled later this year.



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HWIL 99a TEST OBJECTIVES



- Objective 1
 - Assess the ability of the TCES to provide JDN communications.
- Objective 2
 - Assess the capability of the FoS to provide TBM information to the JDN for Engagement, Alerting, and Cueing, and support interoperability per Reporting Responsibility (R²) rules.
- Objective 3
 - Verify the TMD *Interoperability Program Plan* Capability Increment 1 (Air-Breathing Threat only).

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Objective 1 assessed the ability of the TMDSE Link-16 Gateway to accurately emulate the data exchange protocols of the JDN in accordance with MIL-STD-6016 for all appropriate TADIL-J formatted messages. Objective 1 included TSA processing.

Objective 2 assessed the early warning aspect of TBM interoperability using information from JTAGS and AFC to make participants aware of incoming threats before they reached the engagement “envelopes” of the tactical systems. Radar messages were analyzed for timeliness and accuracy to determine if weapon systems could use the information to cue radar.

Objective 3 testing focused on the ability of the PATRIOT and AEGIS systems to successfully engage and intercept ABTs. Each radar system provided information for early warning and cueing.



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HWIL 99a TEST CAPABILITY INCREMENT



- Capability Increment—Operational capabilities are made available to the warfighters in scheduled Capability Increments leading to full capability in 2010
- Capability Increment 1 (Legacy):
 - Objectives based on six Operational Capabilities to defend against ABTs:

Automated Data Management, Cueing, Early Warning, Engagement Coordination, Kill Assessment, and Situational Awareness

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Since each Tactical Segment (for example, PATRIOT) develops its software and operational capabilities at different rates, testing across all systems for segment interoperability cannot occur at once. Therefore, testing occurs in measured advances called Capability Increments.

Capability Increment 1 tested progress for the following operational capabilities:

- **Automated Data Management**—Addresses hostile missile parameters and signatures, rules of engagement, intelligence preparation of the battlespace, friendly system status, critical assets, communications, and other topics related to Joint Theater and Air Missile Defense.
- **Cueing**—Provides track information from one sensor in sufficient detail to allow another sensor to acquire the track earlier than possible with a general surveillance search.
- **Early Warning**—Provides early notification of the launch or approach of unknown weapons or weapon systems carriers.
- **Engagement Coordination**—Ensures the maximum effectiveness of tactical systems by conserving the expenditure of resources on targets already engaged.
- **Kill Assessment**—Relates to defense effectiveness and the need to re-engage a target.
- **Situational Awareness**—Provides the capability to share common, accurate, and unambiguous information among appropriate operational facilities in sufficient time to assess and influence the battlespace but not to execute cueing or engagement coordination.



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HWIL 99a TEST SCENARIOS



- BMDO selected a *Northeast Asia* Scenario
- Scenario variations included:
 - Defense against TBMs
 - Defense against ABTs
- Scenario used threats approved by the BMDO Directorate of Threats and Countermeasures to simulate real world conditions

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To support test objectives and data requirements, the BMDO selected a *Northeast Asia* scenario from the BMDO Directorate of Threats and Countermeasures (DTC).

Two variations of the scenario were prepared, in accordance with DTC guidelines, to ensure testing all aspects of the BMDO requirements. One variation placed AEGIS on the east coast of Korea with a reduced number of TBMs to test active TBM defense. The other variation placed AEGIS on the west coast for better interaction with PATRIOT to defend against ABTs.


The DTC approved the use of the scenario, based on reliable real-world intelligence data, with the following guidelines:

- To maintain the integrity of the threat data, no changes could be made to the threats.
- Threats could be deleted to satisfy the processing limitations of some systems.



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HWIL 99a TEST RESULTS



- Completion rate results
 - Satisfactory completion rate for non-TSA TADIL-J message traffic
 - Completion rate for TSA TADIL-J messages was not satisfactory
- Early Warning results
 - Successful demonstration of receipt and processing of alert and warning messages
- Cueing results
 - Information was not timely and accurate enough for weapons systems to perform cueing
- Reporting Responsibility demonstrated by AEGIS with limited success

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Objective 1 was tested.

Assess the ability of the TCES to provide JDN communications.

- Completion rate results:
 - Satisfactory completion rate for non-TSA TADIL-J message traffic
 - Completion rate for TSA TADIL-J messages was not satisfactory

Objective 2 was tested.

Assess the capability of the FoS to provide TBM information to the JDN for Engagement, Alerting, and Cueing, and support interoperability per Reporting Responsibility (R²) rules.

- Successful demonstration of receipt and processing of TBM alert and warning messages
- Information was not timely and accurate enough for weapons systems to perform TBM cueing
- Reporting Responsibility demonstrated by AEGIS with limited success



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HWIL 99a TEST RESULTS (cont'd)



- Five of six Operational Capabilities for Capability Increment 1 were partially achieved:
 - Early Warning
 - Cueing
 - Kill Assessment
 - Situational Awareness
 - Automated Data Management
- The last OC, Engagement Coordination, was not assessed

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Objective 3 was tested.

Verify the TMD *Interoperability Program Plan* Capability Increment 1 (Air-Breathing Threat only).

- Automated Data Management, Cueing, Early Warning, Kill Assessment, and Situational Awareness were partially demonstrated. Engagement Coordination information could not be exchanged via the JDN.

HWILT 99a successfully demonstrated receipt and processing of alert and warning messages.

PATRIOT provided via the JDN engagement status information which included Kill Assessment.

Weapon systems successfully reported inventory status.

For the operational capability of cueing, there were only four sensors reporting: AEGIS, PATRIOT, CRC and USMC TBMD. THAAD did not report cueing because it does not process J3.2 (Air Track) messages.

Recent upgrades to the CRC JDN implementation resulted in significant track offsets being reported on the JDN.

The Tactical Segments have not implemented the J9.0 capability (TADIL-J messages which carry the coordination of engagements). Therefore, the FoS could not send, receive, or process command and control messages.



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HWIL 99a TEST SUMMARY



- Joint interoperability within the FoS is feasible
- Successful demonstration of FoS capability to participate via the JDN and share information
- Because the Services had not implemented the engagement coordination messages, messages were not exchanges via the JDN

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The Engagement Coordination (J9.1) message has not been implemented by the Services and could not be assessed.



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FUTURE TEST TOOL CAPABILITIES



Future enhancements planned for HWIL interoperability testing include:

- Higher fidelity simulations
- Enhanced database and analysis tools
- Adding an E-3 simulator
- Adding FoS tactical weapon systems (ABL) and sensor platforms (SBIRS)
- Adding Command and Control platforms (TAOC, CIC)
- Expanding JDN services by incorporating more TADIL-J messages

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The interoperability tool will implement higher fidelity simulations in the future to better function with the new systems and capabilities integrated into the Tactical Segments.

The interoperability tool will add automated data reduction and enable better analysis.

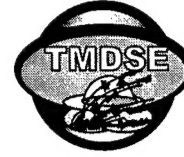
As the FoS expands, the interoperability tool will adopt measures to manage the additional loads imposed by new systems (e.g., expanded communications bandwidth, upgrades to workstations).

The FoS segments will incorporate the J9.0 and J9.1 messages into their operational software to allow more efficient coordination of the active TBM defense against multiple threats.



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FUTURE TESTING AT THE JNTF



- Perform System Integration Test (SIT) risk reduction
 - SIT scheduled in 2001
 - Risk of hardware and software failures decreased prior to next SIT at Kwajalien Atoll
- Support acquisition of PATRIOT PAC-3 (U.S. Army OPTEC)
 - Support PAC-3 IOT&E interoperability testing
- Use TMDSE as the primary tool for interoperability testing to augment Service Operational Requirements Document (ORD) requirements testing

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In future tests, the TMDSE will collect information on planned SIT activities, build a scenario based on this information, run the scenario, and collect the data. JDN performance during this exercise will be used by SIT planners for risk mitigation. The TMDSE data will be compared to data collected after the actual SIT event takes place.

TMDSE will be the primary test tool supporting PATRIOT Advanced Capability-3 (PAC-3) Initial Operational Test and Evaluation (IOT&E) testing, tentatively scheduled for mid-February through April 2001.

OPTEC will validate that PAC-3 meets the interoperability requirements criteria outlined in the *PAC-3 Operational Requirements Document (ORD)*, analyzing data from TMDSE HWIL test runs.



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CONCLUSIONS



- HWIL testing of FoS capabilities, using the TMDSE, will support the acquisition process to enhance interoperability of tactical systems prior to fielding them.
- Interoperability testing uses high fidelity scenarios, hardware, and software so testing emulates the intended use of the Tactical Segments in the theater. This enables military personnel to use their Service-specific combat doctrines for missile defense effectively.
- HWIL testing benefits the warfighter by providing better communications and a better CTP.

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